Organic Light-Emitting Transistors

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Published in:
Pacific Rim Conference on Lasers and Electro-Optics, 2005. CLEO/Pacific Rim 2005

Organic Light-Emitting Transistors

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Abstract

A light-emitting OFET with pronounced ambipolar current characteristic has been prepared by co-evaporation of α-quinquethiophene (α-5T) as hole-transport material and ditridecyl-perylene-tetracarboxylic diimide (P13) as electron-transport material. The light intensity is controlled by both the drain-source voltage V_{DS} and the gate voltage V_G. Here, we demonstrate the general concept of adjusting electron and hole mobilities by co-evaporation of two different organic semiconductors.

Introduction

The successful use of organic materials in organic light-emitting diodes (OLED) and field-effect transistors (OFET) induce the development of more complex and advanced electronic devices based on this class of materials. Combining light emission and transistor characteristics in a single device, i.e., a light-emitting field-effect transistor (LEFET), would not only increase the number of potential applications of organic optoelectronic devices, but also present an ideal structure for degradation studies of organic light-emitting materials under different driving conditions and charge-carrier balances. In order to tune the electron-hole balance as well as the location of the recombination zone between source and drain electrodes, comparable mobility of electrons and holes is required. Such an ambipolar transport is difficult to achieve in a wide-band-gap organic material because of impurity-induced traps [1]. A viable way to circumvent this problem is to mix electron- and hole-transporting moieties into one phase, as was demonstrated with solution processed OFETs [2,3].

In this paper, we report on field-effect transistors based on a co-evaporated film of α-quinquethiophene (α-5T) as hole-transport material and ditridecyl-perylene-tetracarboxylic diimide (P13) as electron-transport material. The two materials have been selected because of their transport and luminescence properties [4,5]. α-5T is known as hole-transporting material [6] and from pure reference devices we extracted a hole mobility of 2.5×10^{-2} cm^2/Vs. P13 belongs to a class of perylene derivatives, which are well-studied electron-transporting materials. The pure reference device had an electron mobility of 5×10^{-3} cm^2/Vs. The electron and hole mobilities of the pure materials differ by less than one order of magnitude. This is a prerequisite for achieving ambipolar current characteristics in a co-evaporated film.

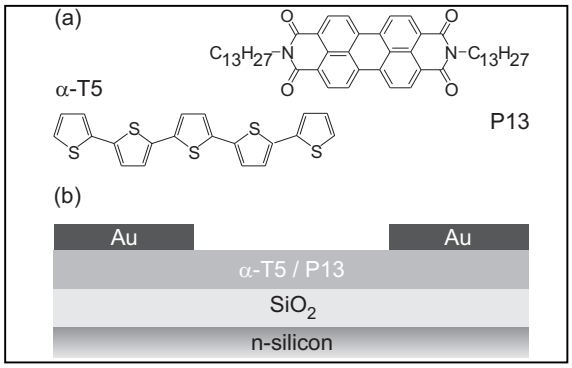

Figure 1: (a) Molecular structure of α-5T and P13. (b) Device structure of the LEFET consisting of a co-evaporated thin film of α-5T and P13.

Results

Figure 2(a) shows the output characteristic of a transistor with a co-evaporated thin film of α-5T and P13. Applying a negative gate bias V_G, typical p-channel characteristics are observed in the third quadrant for negative drain-source voltages. With increasing V_{DS}, an abrupt, steep increase in the drain current I_D is measured, which is a typical characteristic of ambipolar operation in OFETs. This current increase is attributed to the injection of electrons into the organic thin film at the drain contact. A similar behavior is observed for positive gate bias in the first quadrant.
The most striking feature, however, is the light emission monitored by the photocurrent of the photodiode, as shown in Figure 2(b). For negative drain-source and gate voltages, the light out-

put is apparently correlated to the nonsaturating drain current. The highest brightness is achieved for V_G = 0 V and V_{DS} = -50 V. For positive drain-source voltages, only weak emission is observed. In contrast to the negative-voltage case, the emission here occurs at high gate voltages.

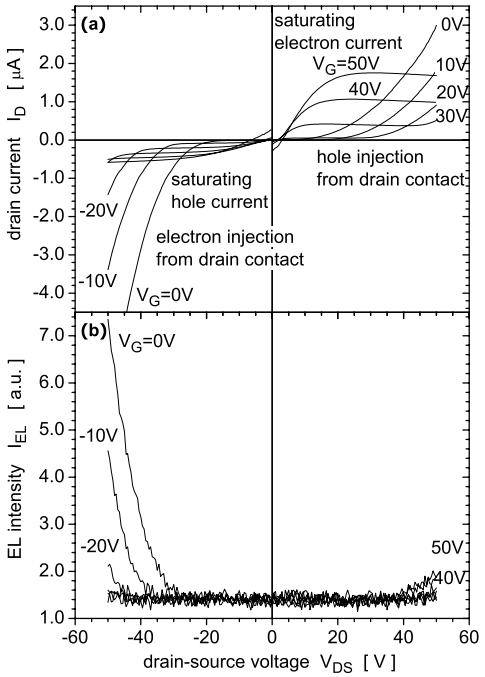

Figure 2: (a) Output characteristics and (b) light intensity for the co-evaporated α-5T/P13 thin-film transistor for negative and positive gate bias.

Figure 3 shows the transfer characteristics of the device. For large $|V_G|$, the current originates either from holes for negative values of V_G or from electrons for positive values of V_G. The square root of the drain current I_D shows the expected linear dependence on V_G, as is known from unipolar devices. Contrary to unipolar devices, where typically a continuous increase in drain current $|I_D|$ is observed for absolute increasing gate voltage $|V_G|$, we observe first a decrease in $|I_D|$ for small values of $|V_G|$, which only starts to increase again after a certain value of $|V_G|$. This current originates in the corresponding opposite type of charge carrier. For increasing drain-source voltages the minimum in drain current shifts towards larger gate voltages. From the linear slope of the square root of I_{DS} vs. V_G, a hole mobility of 10^{-4} cm^2/Vs and an electron mobility of $10^{-3}cm^2/Vs$ can be extracted. Compared with single-layer devices, the hole mobility in α-5T is two orders of magnitude smaller, whereas the electron mobility in P13 compares well with the one in single-layer devices.

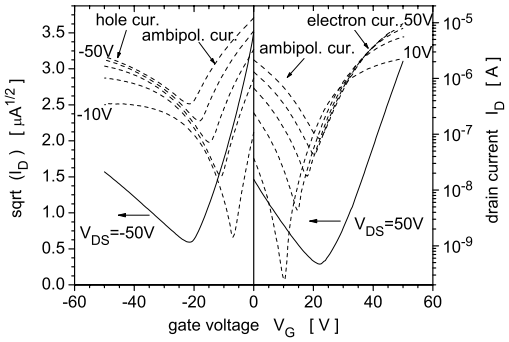

Figure 3: Transfer characteristic of the co-evaporated α-5T/P13 thin-film transistor for negative and positive gate bias. The solid and dashed lines show the square root and the logarithm of the drain current, respectively.

Summary

A light-emitting OFET based on a co-evaporated thin film of α-5T and P13 is demonstrated that exhibits pronounced ambipolar conduction over a wide range of bias conditions accompanied by light emission. Light emission is correlated with the drain current, and can be modulated by both the drain-source voltage and the gate voltage. The device serves as an excellent model structure for a light-emitting OFET and demonstrates that by co-evaporation of two different organic semiconductors, an electron- and a hole-transport material, the electron and hole mobilities can be adjusted.

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